Building Pinball Machines in a STEM Fabrication Course

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Michael L. Hilton

Natural Sciences Collegium, Eckerd College; e-mail: hiltonm@eckerd.edu

Abstract

Pinball machines combine art and engineering in a substantial, yet fun, project well suited for teaching a broad range of maker skills to undergraduate students. The main steps in building a pinball machine are described, along with tips for incorporating this project into the curriculum. Students are very enthusiastic about the project, and it is effective in recruiting STEM majors at Eckerd College. Additionally, it creates a cohort of makers who actively participate in the student leadership of our college makerspace.

Introduction

Eckerd College offers a two-semester, by-invitation course that teaches maker skills to first year students. The first semester teaches CAD, basic digital fabrication (3D printing and laser cutting), microcontroller-based electronics, and computer programming. Students put these skills to use in the second semester by designing and building a significant project. The first few years the course was offered, each student came up with their own project idea. While this allowed each student to pursue their own passion, it often resulted in projects of unequal difficulty or that only used a few of the skills taught during the first semester. To remedy these problems, we switched to having students work in small teams to design and build a pinball machine. Pinball machines combine art and engineering in a challenging, fun project that uses the full range of skills taught in the course.

The main steps in the making of a pinball machine are described in the sections below, followed by remarks describing how students have responded to the project, the instructor's perspective on learning outcomes, and the costs (both in materials and personnel) of building pinball machines.

Concept Design

Most of today's students have never played pinball, so we begin the project with a field trip to a local pinball museum where students play a wide variety of machines to learn about the different mechanisms available to game designers. The most successful pinball machines combine an interesting background story, beautiful artwork, and challenging game mechanics to deliver a cohesive user experience that keeps players coming back for more. Armed with some knowledge of the design space for pinball machines and given a list of commercially available game mechanisms they can utilize in their project, teams design the desired user experience for their machine. This work is typically done on paper or at a whiteboard. Designs are vetted for feasibility by the instructor and critiqued by the other students in the class.

Layout

Commercial pinball machines have two main parts, the playfield and the backboard. The playfield is the heart of every pinball machine; it is the board where the ball rolls around, encountering obstacles and mechanisms such as flippers, slingshots, pop bumpers, and targets. A typical playfield is 21.75" wide by 42" long and made of furniture-grade plywood. The backboard contains a scoring display, artwork, and – in newer machines – often includes a video display. Our course focuses on the playfield, omitting the backboard due to time constraints.

Teams use OnShape to design their playfield. OnShape is a browser-based, professional CAD package that is relatively easy to learn and free for academic use. A library of templates for commercial game mechanisms is provided to students to simplify layout creation.

Playfield Construction

After the layout has been completed and vetted by the instructor, the wooden parts are cut out using a CNC router and the acrylic parts are cut using a laser cutter. The wood parts are glued together as necessary and sanded. The playfield is then painted and decorated. Complex artwork might be inkjet printed on waterslide decal paper and affixed to the surface. Several layers of clear polyurethane are applied to provide a smooth, durable finish. The game mechanisms are then mounted.

Electronics & Wiring

Most game mechanisms are electromechanical, driven by solenoids that are triggered by the pinball activating various types of sensors on the playfield. Like all modern pinball machines, ours use microcontrollers to monitor the sensors and software rules determine which solenoids to fire, LEDs to

light, sounds to play, and points to award.

We use three Arduino Nano microcontrollers in our pinball machines: one for controlling the solenoids; one for handling the non-solenoid elements; and one for displaying the score and playing sounds. These computers are connected in a simple network, allowing them to share information. This design was chosen for three reasons. First, a lot of GPIO pins are needed, and using three Nanos is cheaper than using one Arduino Mega. You will probably end up frying at least one Arduino at some point and replacing a Nano is cheaper than replacing a fancier Arduino. Second, using multiple computers reduces the latency of responding to events on the playfield. Third, the code for controlling solenoids is quite tricky. If you leave a solenoid energized for too long, it will melt. Isolating this code on a separate computer prevents introducing software bugs that lead to hardware failures.

Solenoids require currents much larger than can be supplied directly by an Arduino, so a solenoid driver circuit board is connected between the Arduino output pins and the solenoids. To protect the Arduino input pins from high voltages and currents, opto-isolator circuit boards are connected between the Arduinos and the sensors. Custom circuit boards were designed by the author, manufactured using commercial service, and assembled by the students.

Wiring (and subsequently debugging the wiring) is one of the most time-consuming stages of the build process. Many teams initially ignore the instructor's tips on topics such as color-coding wires to aid debugging and being disciplined in organizing and routing wires, much to their chagrin. Experience is a great teacher!

Software

Although students learn basic Arduino programming in the first semester, programming a pinball machine is well beyond the ability of most students. The instructor provides the source code for a generic pinball machine, which can be tailored to a specific machine design using configuration files. The software can also be modified to implement custom game behaviors or scoring rules; this is typically done by the instructor or teaching assistant.

Results

The improvement in student skills and confidence over the course of the semester is remarkable. The first two weeks of construction are chaotic, with students continually asking for help and reassurance with each step. By the third week of construction, teams can work mostly on their own after being given the week's goals, and towards the end of the semester they set their own weekly goals. Students finish the semester with a party and invite their friends to drop by and play their creations.

Students are very enthusiastic about the project, rating it highly in the formal course evaluation. The maker course has also been successful in recruiting course participants to major in physics, math, or computer science. An additional benefit has been the creation of a cohort of makers who actively participate in the student leadership of our college makerspace.

Costs

The materials cost of each pinball machine is roughly $1500. This cost can be amortized over several years by reusing parts that are still in good condition. In addition to the instructor, we use one teaching assistant for each three or four teams, usually hiring students who have taken the course in the previous year.

We have found that teams comprised of two students work best – three students at most. The playfield is not large enough for more than two people to work on it at the same time, and the amount of effort required to build a machine is enough to keep two people busy an entire semester, but not three (and idle hands in a lab course is never a good thing…).

Concluding Remarks

Building pinball machines is a fun and rewarding educational experience for the students and instructors alike. I love teaching this course. However, it is a lot of work. Before incorporating the building of pinball machines in a course, you *absolutely must* make one yourself, so you thoroughly understand the process and realize what you are getting into. To help you get started, I have posted detailed instructions, software, and printed circuit board designs online at

https://github.com/hiltonml/pinball